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Advancing UAV Video Transmission: A Full-Duplex System with RF and Signal Processing for Reliable, Long-Range HD Communication

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Abstract

Unmanned aerial vehicles (UAVs) have transformed industries by enabling advanced aerial imaging and data collection. However, transmitting high-definition (HD) video from UAVs to ground stations poses challenges such as limited range, bandwidth constraints, and interference. This paper presents the development of an HD, full-duplex video transmission system using cutting-edge electronic technologies, including advanced radio frequency (RF) systems and signal processing. These electronic systems are designed to ensure fast, reliable, and interference-free video transmission over long distances. The research explores key electronic concepts such as full-duplex communication, channel modeling, signal processing techniques, and interference cancellation, which are critical for building efficient UAV video transmission systems. The research also explores key electronic principles, such as channel modeling, which simulates how signals travel through the air, and interference cancellation, which helps eliminate overlapping signals. These technologies work together to improve the performance of the video transmission system, ensuring it remains efficient and reliable in challenging environments. Overall, this paper highlights the importance of integrating advanced electronics and communication systems to overcome the challenges of drone video transmission, paving the way for more effective and versatile UAV applications.

Keywords: Camera, Zedboard@7000, AD9361, wideband dipole antenna, radio frequency (RF)

INTRODUCTION

Unmanned aerial vehicles, or UAVs, are gaining popularity for applications such as surveillance, building inspection, and aerial photography and videography. Transmitting high-quality video without any delays in real time is a significant challenge, though. The slowness of traditional analog systems, which can have delays of several seconds, and their susceptibility to interference, which lowers visual quality, are common problems.

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Video transmission via software-defined radio (SDR) is a more recent solution to this issue. Instead of using conventional hardware to generate and control radio signals, SDR technology uses software, which increases its adaptability and dependability. These systems are adaptable to meet requirements, deliver crisp, high-definition video with little lag, and function well even under challenging circumstances. Additionally, they are highly versatile due to their ability to operate across several frequencies and bandwidths.

The Analog Devices AD9361 RF transceiver is a notable example of this technology, since it has demonstrated exceptional efficacy in SDR-based

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video transmission. Technology is transforming drone use by allowing drones to transmit high-quality, real-time video feeds. It creates new opportunities for uses such as video production, aerial photography, and industrial inspections, increasing the dependability and adaptability of drones for a variety of jobs.

This technology opens new opportunities for drone operations while also addressing the drawbacks of conventional analog systems. SDR-based technology is expected to transform drone use across industries by providing high-quality, interference-free video transmission, making drones even more effective, dependable, and adaptable.

WIRELESS TRANSMISSION SYSTEM

The basic components of full duplex video transmission are a camera, FPGA (field programmable gate array), AD9361, and a wideband dipole antenna, as shown in Figure 1.

Camera

Cameras should have a resolution of at least 720p for excellent video quality, but 4K or 8K is much better for the crispest shots. Additionally, the camera should record at 60 frames per second or faster to maintain fluid and continuous action. To ensure that the video is clear even in difficult or dark lighting, it is also crucial to operate well in low light. These characteristics ensure clear and reliable video in a variety of scenarios, making high-quality cameras ideal [1].

FPGA ZedBoard@7000

The ZedBoard is a flexible and reasonably priced development platform based on the Zynq®-7000 SoC, which blends potent ARM and FPGA processing capabilities. Both engineers and enthusiasts who wish to prototype or create new goods can use it. The board has a Xilinx Artix-7 FPGA, a dual-core ARM Cortex-A9 processor, 1 GB of RAM, and several practical ports, including general-purpose input/output (GPIO), Ethernet, USB, and HDMI. A microSD card slot, a JTAG connector, and more expansion ports are also included.

ZedBoard is a popular choice for many different applications because of its many capabilities and versatility, making it an excellent choice for someone just starting out with FPGA and ARM development. The AD9361 transceiver is a high-performance radio frequency transceiver that is perfect for transmitting UAV video because of its broad frequency range of 70 MHz to 6 GHz, high data throughput of up to 500 Mbps, and low latency.

Additionally, its power efficiency and tiny form size make it ideal for UAV applications [2]. Integrated frequency synthesizers, digital signal processing (DSP) capabilities, and a versatile processor interface are just a few of the other features that the AD9361 offers. A microcontroller or FPGA is frequently used in conjunction with the AD9361 to manage its settings and handle the digital data it produces.

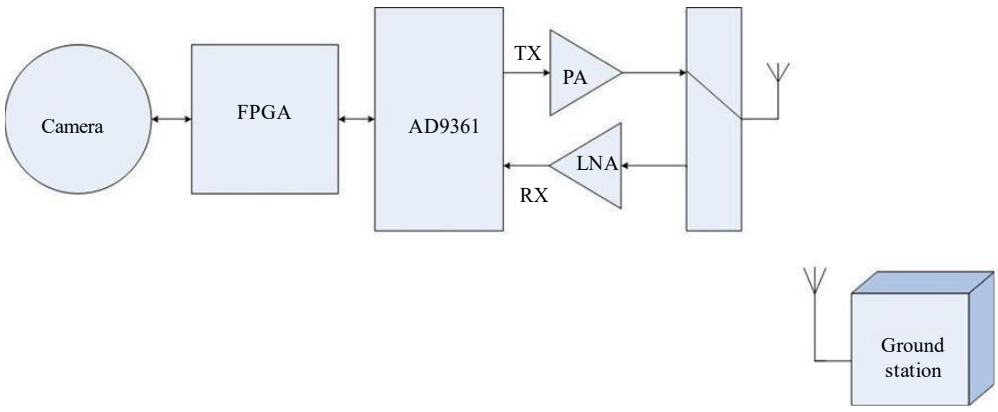

Figure 1. Block diagram of wireless video transmission.

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Low Noise Amplifier and Power Amplifier

The signal quality is improved by a low noise amplifier (LNA), which helps to amplify weak signals that the antenna receives before processing. As a result, the receiver performs better and becomes more sensitive. via boosting the signal before it is transmitted via the antenna, a power amplifier (PA) helps to increase the transmission's power and range. The LNA in UAV video systems boosts the video signal from the UAV camera, and the PA fortifies the signal before sending it back to the ground station. Selecting the appropriate LNA and PA is essential to improving the system's range, dependability, and video quality [3].

Wideband Dipole Antenna Array

Multiple dipole antennas organized in a particular arrangement make up a wideband dipole antenna array, as seen in Figure 2. It can operate throughout a wide frequency range, from 4 to 6 GHz, which makes it appropriate for several applications that call for frequency flexibility [4, 5].

Although there are various approaches to designing wideband dipole antenna arrays (WDAAs), they all share certain characteristics. To get the appropriate radiation pattern and frequency range, the dipole antennas are first placed in a particular manner. Second, to minimize mutual coupling, the antennas' power supply is optimized. Mutual coupling can distort the signal from the antenna and reduce the array's overall efficiency, hence this is very important.

Ground Station

A drone's transmission system relies heavily on its ground control station (GCS). It functions as the operator's interface with the drone and the primary control center for drone operations. The drone's equipment, including the camera and other payloads, may be controlled and the operator can monitor the drone's performance while in flight from the GCS.

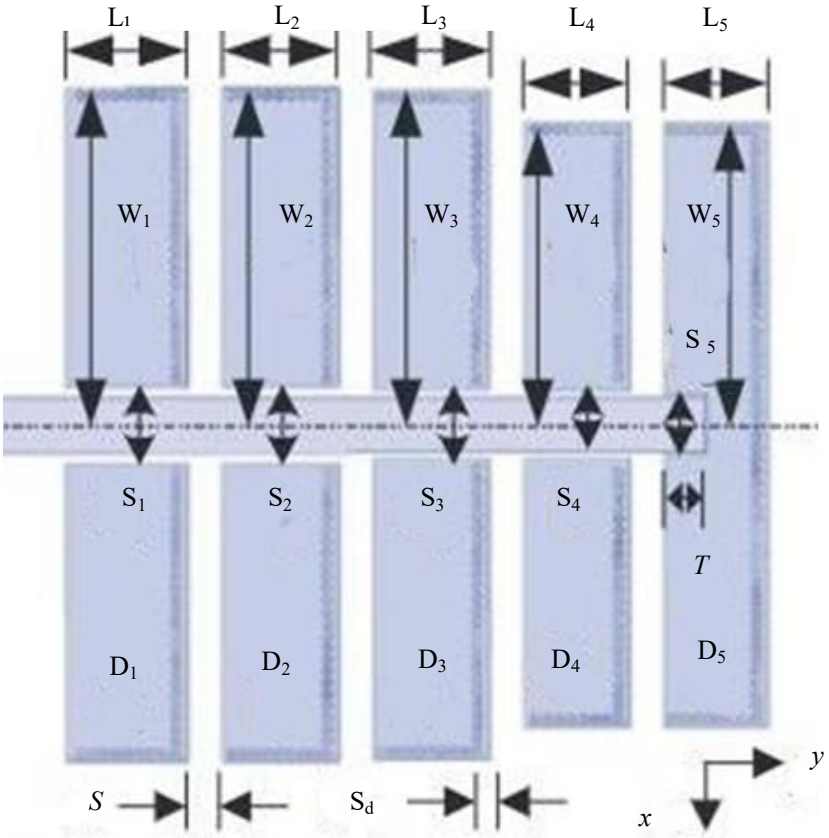

Figure 2. Wideband dipole antenna.

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LITERATURE REVIEW

Innovative solutions in data processing, transmission, and remote sensing are becoming indispensable in many industries because of the rapid evolution of technology. Enhancing a cellular-connected UAV system is the main goal of this research. Through the integration of FPGA-based frameworks for UAV control, real-time video streaming, and sophisticated signal processing, the project seeks to develop a high-performing and adaptable system. The project incorporates expertise from several fields, such as advanced UAV control frameworks, signal analysis, high-speed camera development, hardware features, SDR implementation, and real-time video streaming. The project's shape is greatly influenced by this joint expertise, which makes it both creative and informed.

In a study by Zhou et al. [6], the authors examined how a cellular network, namely LTE, may be used to control and transmit video in real-time from UAVs (drones). They set up a test to transmit control signals from the ground to the drone (downlink) and video from the drone to the ground (uplink). Their trials showed how crucial elements like connection reliability, network adaptability, and signal strength are to ensuring the system functions properly. The findings provide valuable information for developing more effective drone control and cellular network video streaming systems.

Girish Chandra Tripathi and colleagues [7]. used an FPGA platform to create a digital pre-distortion algorithm for a low-cost solution. The system is intended to enhance performance in wireless communication and military applications. It makes use of the Xilinx Zynq 7000 boards and the AD9361 radio frequency (RF) transceiver. Their research demonstrates the potential of FPGA technology to develop high-performance systems at a reasonable cost for a variety of applications, such as SDRs and RF testing.

Pragati G. Rashinkar and Nitesh Guinde [8] used Avnet's ZedBoard Zynq-7000 and Analog Devices AD9361 to show how a SDR on FPGA hardware works. They used MATLAB and Xilinx's System Generator to create the system, demonstrating a versatile SDR platform for wireless communication.

Runjiang Dou et al. [1] created a high-speed CMOS (complementary metal-oxide semiconductor) camera that transmits data effectively and assesses image quality in real time. For reliable, quick picture processing, the camera combines FPGA technology with a CMOS image sensor.

Using an enhanced KLT feature tracker, Qunfang He et al. [9] presented a UAV return architecture. They employed optimization techniques to build a hardware acceleration architecture and a FPGA to lower the computational complexity.

Chi Sun Yu and colleagues [2]. presented a switchless bi-directional amplifier in which the LNA and PA are coupled directly. Their experiments showed that this design outperforms independent amplifiers without the usual loss, expense, or size increase associated with switching.

Using a unique 0.15-μm GaAs pHEMT technology, Hsien-Chin Chiu and Bo-Yu Ke [3]. worked on millimeter-wave circuit design. They examined both active and passive parts, such as a low-loss RF amplifier and an on-chip slow-wave transmission line. Their V-band results demonstrated that the device operated effectively with minimal noise.

PROPOSED SYSTEM

After the UAV records video with its camera, an FPGA compresses the video using a video encoding technique such as H.264 or MPEG-4. Using a transceiver, the encoded video is transmitted to the ground station (AD9361). After being received at the ground station, the video is decoded using the same technique as the UAV and shown on a monitor [10–15].

Interfacing of Camera With FPGA

An FPGA requires the camera module to be connected to the device, as well as the setup of the required hardware and software for taking and processing picture data. Usually, this data and setting up

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the camera's interface (such as MIPI or parallel) and developing FPGA code to manage the camera, process image data, and carry out operations like object recognition or filtering. Images that have been processed can then be sent or seen. To interface effectively, memory management, synchronization, and data bandwidth must all be carefully considered. In domains where real-time image processing is essential, such as robotics, computer vision, and industrial automation, this is particularly significant.

Interfacing of FPGA to AD9361

The AD9361 RF transceiver chip must be connected to the high-speed data interfaces of the FPGA, such as JESD204B or LVDS, as seen in Figure 3. With this configuration, the FPGA and the AD9361 can exchange data in both directions, enabling the FPGA to manage the transceiver and process the RF signals it receives. This connection can also be facilitated by SDR platforms such as the Xilinx Zynq, which combine the FPGA and ARM CPU to provide a single environment for creating SDR applications. The FPGA is then configured to manage the RF functionalities of the AD9361, which makes it a crucial part of contemporary SDR and wireless communication systems.

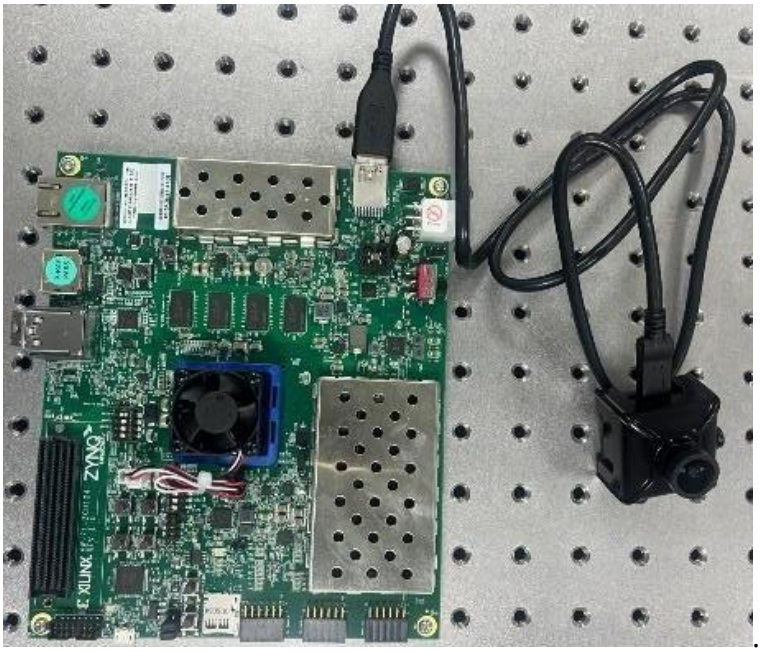

Figure 3. Interfacing of camera with field-programmable gate array (FPGA).

Figure 4. Interfacing of AD9361 With field-programmable gate array (FPGA).

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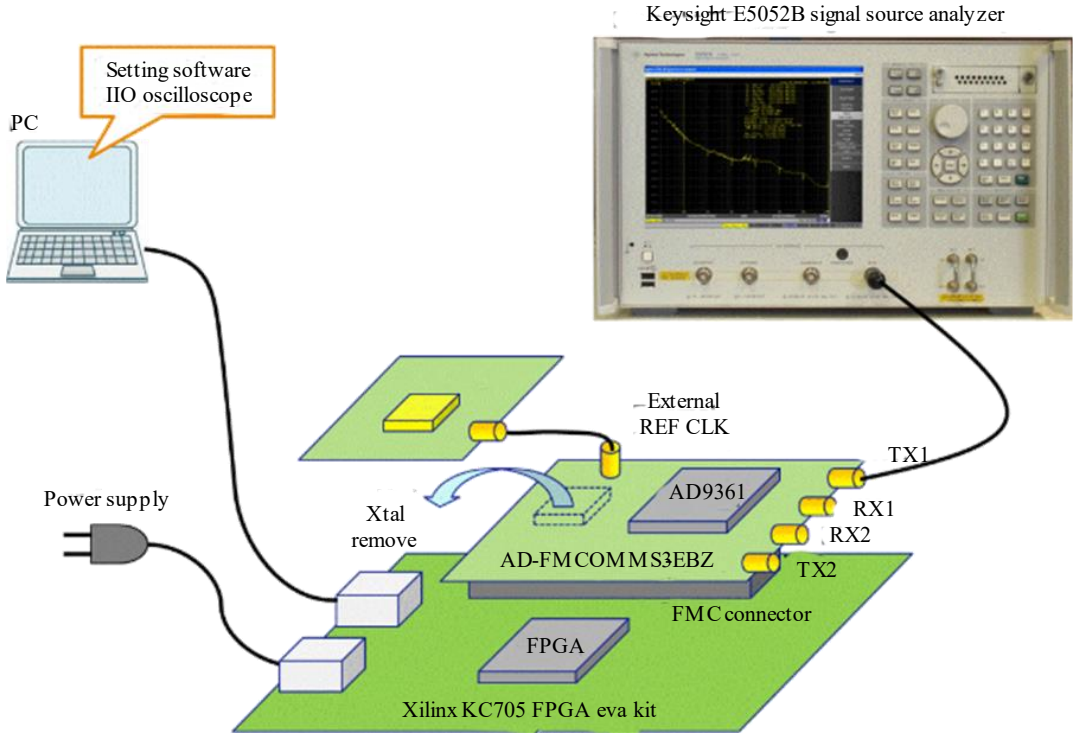

Figure 5. AD9361 evaluation system.

The AD9361 reference board (AD-FMCOMMS3-EBZ) was tested by EPSON utilizing their external reference clock, the TCXO TG5032CAN. To verify if the TCXO and TX LO combined phase noise met the requirements in the AD9361 datasheet, they evaluated the phase noise at 800 MHz and 2.4 GHz. Figure 4 depicts the AD9361 evaluation system. Figure 5 compares the expected phase noise from ADI with the phase noise from the TG5032CAN 40 MHz oscillator, both with and without a filter. Figure 6 Shows the phase noise comparison of TG5032CAN 40MHz oscillator with/without filter and ADI expected phase noise.

Phase noise data is as follows:

- TG5032CAN 40 MHz without filter
- TG5032CAN 40 MHz with filter
- Expected spec for 40 MHz.

Channel Loss Model

In wireless communications, a mathematical tool called a channel loss model see in Figure 7 is used to calculate the power reduction that takes place during signal transmission across a wireless channel.

Signal loss in wireless communications is caused by several factors:

- *Distance*: The farther the signal travels, the more power it loses.
- *Environment*: Obstacles like buildings, trees, and hills can reflect, scatter, or bend the signal, leading to power loss.
- *Frequency*: Signals at higher frequencies tend to experience more power loss compared to those at lower frequencies.
- *Antenna height*: A higher antenna reduces the amount of power loss.
- *Terrain*: Different terrains impact signal loss, with urban areas typically experiencing higher loss than rural areas.
- *Weather*: Weather conditions such as rain, fog, and snow can also contribute to greater signal loss.

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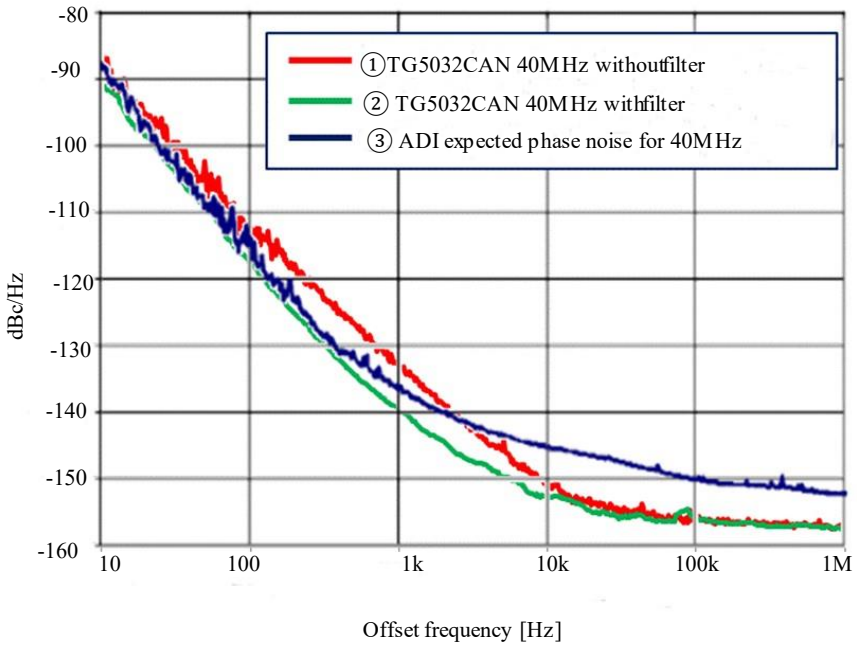

Figure 6. Phase noise comparison of TG5032CAN 40 MHz oscillator with/without filter and ADI expected phase noise.

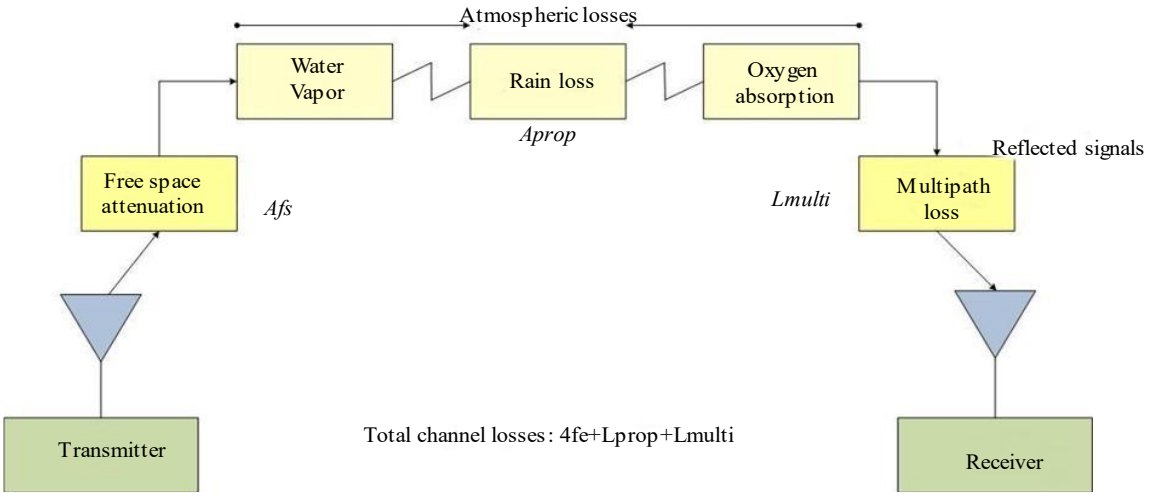

Figure 7. Channel loss model.

Figure 7 displays the channel loss model for wireless communication. Using the minimal signal (Smin) needed to receive and analyze the information from the transmitter, we can determine the sensitivity of the receiver [14–17]. The receiver sensitivity is -95 dBm in this instance. After determining this sensitivity, we may use several variables to determine the signal's maximum range:

- *(S/N) min*: The minimum signal-to-noise (S/N) ratio needed to process the signal.
- *NF*: The noise figure, which shows how much noise the receiver adds.
- *K*: A constant called Boltzmann's constant.
- *T0*: The temperature of the receiver's input, which is usually 290 K.
- *B*: The bandwidth of the receiver, or how much signal it can process at once.

CONCLUSION

The AD9361 RF transceiver and an FPGA are used in this research to demonstrate a novel method of wirelessly transmitting high-definition video. This approach is more dependable than conventional

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ones since it employs two-way communication to minimize delays and can effortlessly move between various frequency bands. It also lowers the likelihood of failure by establishing a more robust and reliable wireless connection. Development is accelerated and a speedier, low-latency connection is guaranteed by the two-way system. For sectors like agriculture, power-line inspection, and surveillance that require dependable, secure communication, this strategy is ideal.

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